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Polariton spontaneous emission superradiance in III–V semiconductor doped with quantum wells or quantum dots

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The most interesting phenomena in photonic band gap materials are the formation of photon-atom bound states and suppression of spontaneous emission from the photon-atom bound state [1]. Recently, Rupasov and Singh have studied the quantum electrodynamics of a two-level atom placed within a frequency dispersive medium whose polariton spectrum contains a energy gap [2]. They found that if the atomic resonance frequency lies within the gap, then the spectrum of the system contains a polariton-atom bound state with an eigenfrequency lying within the gap. The radiation and medium polarization of the bound state are localized in the vicinity of the atom. In photonic band gap materials, the existence of the photonic band gap is due to multiple photon scattering by spatially correlated scatters, while in dispersive media such as semiconductors and dielectrics, the energy gap is caused by photon coupling to an elementary excitation (excitons, optical phonons etc.) of the media.

The aim of the present paper is to study the spontaneous emission rate of photons for III–V semiconductors doped with N two-level atoms. Here the two-level atom represents a quantum well or a quantum dot. Making use of the spherical harmonic representation and the dipole resonance approximation, we derive an effective model Hamiltonian of the system, which, in the limiting case of empty space, coincides with the model Hamiltonian obtained in the liturature. To find the self-energy function of the system, we diagonalize exactly the Hamiltonian in the one-polariton sector of the entire Hilbert space. To study the spontaneous decay rate of the initially excited atomic states of the polariton-atom system, we consider the atomic resonance frequencies of the atoms lie either inside the polariton gap or the polariton continuous spectra. For $N = 2$, we found that the spontaneous decay rate and superradiant effects as follows. We consider the case in which one atom is in the excited state while the other is in the ground state with no polaritons present in the system and the atomic resonance frequencies of two atoms lie in the polariton continuous spectra. It is found that when the interatomic distance between the atoms becomes very large, the spontaneous decay rate of the excited atomic state is equal to that of the single atom case. For very small interatomic distances, it is found that the rate of spontaneous emission from the symmetric state is two times that of the single atom case. This phenomenon in quantum optics is called superradiance. For the polariton-atom system in the antisymmetric state, the spontaneous emission rate is found to be zero. This phenomenon is related to subradiance in quantum optics. Numerical calculations are performed for the spontaneous decay rate of an excited atomic state in GaSb and GaAs. Non-equilibrium and nonlinear effets have also been studied.

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